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LOW-GRAVITY FLUID MECHANICS DROP TOWER FACILITY

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16. Abstract

The George C. Marshall Space Flight Center low-gravity simulating drop test facility is described. The design of the drag shield, test package, guide rails, stopping mechanism, control system and instrumentation are discussed. The operating characteristics and measured results obtained during operational check-out are reported. Problems encountered and future plans are described.

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LIST OF SYMBOLS

Symbol	Definition
a	Acceleration/Deceleration, ft/sec^2
C_D	Drag coefficient drag shield, Dimensionless
D	Diameter, ft
g_o	Earth gravitational constant, 32.142 - ft/sec^2
h	Drop height, ft
S_s	Stopping distance, ft
t	Time, sec
V	Velocity, ft/sec

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SUMMARY

A drop tower was designed and built at Marshall Space Flight Center to investigate Saturn S-IVB stage orbital propellant behavior and assure satisfactory propellant conditions for orbital engine restart. The drop height of approximately 300 feet provides a low gravity environment for 4.3 seconds. Because of the unprecedented drop height and weight (4000 lbs) of the test capsule a unique pneumatic device was designed to decelerate the capsule without damage.

The low gravity simulation drop test facility is described. The design of the drag shield, test package, guide rails, stopping mechanism, control system and instrumentation are discussed. The operating characteristics and measured results obtained during operational check-out are reported. Problems encountered and future plans are described.

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INTRODUCTION

Although applicable to fundamental research in low gravity fluid mechanics, heat transfer, and many other fields, the primary purpose of the MSFC Low Gravity Fluid Mechanics Drop Tower Facility is to support the Saturn V/S-IVB stage design. The S-IVB lunar mission requires an extended low gravity orbital coast period with a subsequent restart of the main propulsion engine. Prior to the S-IVB-203 flight and recent S-IVB Saturn V flights there was a significant lack of knowledge concerning the low gravity fluid behavior phenomena the S-IVB would encounter in orbit.

The value of drop tower facilities such as the MSFC facility is apparent when alternate means for investigating low gravity fluid behavior are considered (airplanes flying a Keplarian trajectory or orbital experimentation). However, drop towers do have the disadvantage of relatively short low gravity test durations. The drop towers available at the time the facility design was initiated (mid-1964) were less than 100 feet in height and provided test times of approximately 2.6 seconds or less. The study of reduced gravity liquid behavior with such test durations often limited test container sizes to one inch or less. This "test tube" size made scaling to S-IVB stage dimensions (260 inches) difficult, if not impossible. The MSFC drop tower facility provides about 4.3 seconds of test time and permits the use of 6-inch to 8-inch diameter tank models.

Other large drop tower facilities were under consideration or development at the time the MSFC facility was being designed. However, these facilities were not expected to be available in time to support the Saturn V program. It was possible to develop the MSFC facility on a timely basis because the availability of the 360-ft Saturn V dynamic test stand eliminated the need for construction of a special tower.

DROP TOWER DESIGN REQUIREMENTS

The basic elements of a typical drop facility consist of a tower, drag shield, experiment package, and decelerating device as illustrated by Figure 1. The experimental package usually is suspended at the top of the drag shield, which in turn is suspended from the top of the tower. As the package/shield combination is released, the drag on the shield causes it to drop at a slower rate than the package. Immediately prior to the drag shield arrival at the bottom of the drop tower, the package settles on the floor of the drag shield. The drag shield nose then impacts into some shock absorbing material that brings both components to rest at relatively moderate deceleration rates.

The facility under consideration was to be installed in an enclosed test stand that was constructed to dynamically test the Saturn V Apollo Vehicle. This test stand could easily accommodate a drop facility with a free-fall height of approximately 300 ft. Figure 2 shows free-fall distance and velocity as a function of time and illustrates that a drop height of 300 feet results in a free-fall time of approximately 4.35 seconds. As discussed in the Appendix, it was anticipated that this test duration would allow testing of a six-inch model.

From the range of problems requiring investigation for proper support of the Saturn V program, the following facility requirements were established:

<u>Fluid motions to be studied</u>

- interface formation
- slosh wave behavior
- drain termination
- liquid-vapor sensor reliability

Low gravity levels desired

- minimum 1×10^{-4} $g_o \pm 5 \times 10^{-5}$ } (including all intermed-
- Maximum 4×10^{-2} $g_o \pm 5 \times 10^{-3}$ } iate levels)

Model tank diameters

- 6 inches or more

These requirements caused the complexity, size and weight of the drag shield and experimental package to be greater than those of other facilities, and thus several problems were anticipated. In particular, the relative motion of the drag shield and experimental package and the deceleration of the drag-shield/package combination appeared to be major problems.

For example, at an acceleration level of 1×10^{-4} g_o, the package will have dropped 12 feet farther after 4.35 seconds than it would have at 4×10^{-2} g_o. Since obtaining a maximum low gravity time is of primary importance, the package could not be allowed to touch the drag shield floor midway through the drop. This dictated a shield with a very low drag for use at (1×10^{-4} g_o) and a relatively high drag for use at (4×10^{-2} g_o).

Most of the drop towers in operation at the time the MSFC facility was in the conceptual design phase used spikes driven into sand or wheat, or a rounded nose impacting into cardboard or other crushable material, as a means of deceleration. Figure 3 shows the stopping distance versus drop height for various uniform deceleration levels. Assuming frictionless free fall and uniform deceleration (2), the stopping distance (S_s) can be related to drop tower height (h) by:

$$S_s = \frac{h}{a}$$

Most facilities had peak deceleration levels of approximately 20 g_o to 25 g_o. These forces were not uniform but varied over the stopping distance. Assuming that these deceleration levels might be equivalent to a uniform deceleration of approximately 15 g_o, the stopping distance required for a 100-foot drop tower would be approximately 6 1/2 feet and is considered reasonable; however, for a 360-foot drop tower, this distance would be approximately 25 feet. Thus, the usual methods of deceleration were considered impractical and an extensive investigation of deceleration methods was required.

FACILITY DESCRIPTION

The MSFC drop tower was designed to satisfy the requirements enumerated previously. Figure 4 is a composite showing various physical characteristics and capabilities of the facility. The facility consists of the same basic components used in other drop towers, that is, a drag shield, experimental package, and deceleration device. However, the MSFC tower does have some operational characteristics that are unique. The experimental package is not attached in any manner to the drag shield and rests on the drag shield floor until drag shield release. The package has a high pressure nitrogen thrust system which provides the desired acceleration level during the test period. Prior to drag shield release the package thrust is initiated so that upon release the shield falls faster than the package and the two components descend as separate units. Before the shield deceleration begins, however, the package must settle on the shield floor so that the two components decelerate as one unit and damage to the package is prevented. Therefore, the relative distance between the package and shield floor must be carefully controlled. The shield is equipped with a removable drag brake and thrust system to enable control of the relative package/shield travel.

A unique concept was conceived to enable acceptable deceleration of the drag shield/package combination. The deceleration device consists of an open cylindrical tube that enables the drag shield to compress the air within the tube and thereby provide the stopping force. Major advantages of this device are the capability of immediate reuse and the low maintenance costs. Use of the device did, however, necessitate the use of guide rails to guide the shield into the tube.

Details concerning the major tower components are outlined in subsequent sections.

Drag Shield

The drag shield weighs 3,620 pounds and, as shown in Figure 4, is composed of three sections; a hemispherical nose for aerodynamic fairing, a cylindrical center section providing a clear test bay approximately 6 feet in diameter by 8 feet long, and a tail cone section that houses the fixed equipment and provides aerodynamic fairing for reduced drag.

The cylindrical center section consists of a structural steel floor and roof structure joined by four structural T-sections positioned 90° apart and is covered with three-sixteenth-inch thick aluminum. The center section contains a recess that provides guide rail clearance. A bronze guide rail bearing assembly is installed at each end of the recess. The drag shield contacts the guide rails only at the bearing assembly, which is adjusted to provide one-half-inch clearance on the rails. A five foot wide door provides access into the center section. Originally, a full-length plexiglas window was on one side, but the plexiglas was eventually replaced with aluminum. The nose and the center section are designed to withstand an external pressure load of 15 psig and the floor in the center section is designed for the impact of a 500 lb object (3 feet by 3 feet contact area) at 25 g's.

A cavity within the drag shield of approximately 6 feet diameter by 8 feet high is provided for experiment package movement. The drag shield is of aerodynamic shape with a length-to-diameter ratio of approximately three, to be compatible with the minimum required experiment acceleration level of $1 \times 10^{-4}\ g_o$.

The tail cone section provides housing or mounting structure for equipment associated with the drag shield release, rate of descent, and telemetry control apparatus. With the exception of the telemetry system, the equipment arrangement is illustrated in Figure 5. The release apparatus consists of a pneumatic "ball-lock" quick release mechanism operated by 750 psig nitrogen supplied through a regulator from 3000 psig storage bottles.

As mentioned previously, the rate of drag shield descent is controlled to a limited degree by a removable drag plate and by a thruster system. The drag plate is a seventy-inch diameter aluminum disc.

The thruster system is composed of four thrust nozzles operating in pairs and can provide thirty pounds thrust per nozzle for approximately five seconds. The nozzles can provide thrust in either direction and each pair can be sequenced for the desired initiation and cutoff time.

Figure 6 shows an early prediction of the relative displacement of the experimental package and the drag shield. Also shown is the predicted drag on the drag shield and a schematic of the package displacement. The assumed thrust on the internal package was approximately 10 pounds and created an upward acceleration of .032 g_o on the experiment. As illustrated in the figure, the package was expected to rise from the floor and then settle back before the shield entered the stopping tube.

Catch Tube

The catch tube (illustrated in Figures 7 and 8) is constructed of three-eighths-inch thick steel plate rolled to an inside diameter of 7 feet 6 inches $\pm$ 1/4 inch and reinforced with external hoops of rolled steel angles. The tube is 40 feet long and is provided with seven pairs of variable orifices and one pair of fixed orifices distributed along its length. The orifices enable control of air pressure within the tube (deceleration energy) and prevention of drag shield "rebound".

Ten circumferential rubber seals are installed, one at the top of the tube, one above the top orifice, one between each orifice, and one below the bottom (fixed) orifice. These seals are rubber extruded into angle shapes, with legs of four inches and 1 1/2 inches, and are held in place with machine screws through a backup ring. With the four-inch leg outstanding and a 1 1/2-inch clearance between the drag shield and the wall of the tube, a sealing surface approximately 2 inches wide is provided on the drag shield.

The bottom of the tube contains approximately 5 feet of commercial packing material to absorb any drag shield residual velocity.

Guide Rails

The close clearance between the drag shield diameter and the stopping tube (1 1/2 inches on the radius) necessitated guidance of the shield throughout the entire drop. To accomplish this, a set of rails was installed the entire length of the tower. The clearance between the rails and the housing on the drag shield is such that the drag shield drops freely without touching the rails. The rails, which are structural T-beams, were designed for 8,000 pound and 4,000 pound impact loads normal to and parallel to the rail, respectively.

Test Package

The test package is shown in Figure 9. This particular package consisted of a steel angle frame 3 feet by 3 feet by 18 inches tall with a plywood floor. The following major components were mounted within this frame: a 16 mm high-speed movie camera; 250 watt lamps for camera lighting; a Lucite test tank with light shield; a high pressure gas thruster system (consisting of a pressure bottle, regulator, solenoid valve and a sonic nozzle); a high-g and low-g accelerometer; a pressure transducer for determining thrust level; battery power packs for camera, lights and accelerometer operation; and a control box. The package weight was approximately 260 pounds.

Control System

A control system schematic for the facility is shown in Figure 10. The basic electrical controls consist of a central control console and a 30-volt motor-generator. Both are mounted on the stand at the 336-foot level.

The central control console consists of a group of DC switches and indicating lights. The purpose of the control console is to check out components, conduct sequences, and initiate actual test sequences via a quick-disconnect control cable to the aeroshield.

The 30-volt motor-generator provides temporary power to the facility. It is disconnected shortly before test start and the systems are manually switched to the aeroshield battery packs and telemetry system.

The control system on board the aeroshield incorporates a timer-relay board containing control relays and time delay relays which operate, individually as well as sequentially, various solenoid valves and components of the aeroshield. The timing sequence begins when the "SEQUENCE START" master switch on the control console is manually thrown to the "START" position.

In addition to the basic control system on the aeroshield, there is a 30-volt DC battery pack on the test package which provides power for the test package components. These components are controlled by a universal timer/relay control box mounted on the test package. The test components are independent of stand control once the initial "SEQUENCE START" signal is given. When the "SEQUENCE START" signal picks up a relay on the test package the universal timer is energized which, in turn, provides power for the various package functions (camera, lights, solenoid valves, transmitters, etc.). The universal timer also incorporates a timing relay that cuts off the system after a preset time delay.

A block diagram of the control system is illustrated in Figure 10.

Instrumentation

Formerly the recorded data were obtained by means of a trailing cable between the test stand and the aeroshield; however, the trailing cable system was replaced with a telemetry system which provides more measurement channels and eliminates all connections between the package and the aeroshield.

ANALYTICAL FACILITY MODEL

To verify the feasibility of the drop tower and to predict its performance characteristics, a mathematical model that describes the relative motion between the package and drag shield and the performance of the catch tube was developed. The model treats the drag shield and package as separate falling bodies, that is, thrust on the package as well as thrust and retarding forces (aerodynamic drag and rail friction) on the drag shield are considered. Also, the variation in catch tube orifice area as the drag shield enters the tube is considered.

The model equations were programmed for solution by a digital computer. A detailed discussion of this computer program and a comparison of its results with experimental data is presented in Reference 1.

FACILITY CHECKOUT

Test Plans

The checkout of the test facility consisted of two major phases. The first phase was to assure that the drag shield, rails, and catch tube would meet the design requirements and operate successfully as an integrated system. Thus, the initial series of drops were conducted starting at a height just above the catch tube and proceeding in increments up to the top of the tower. The test data, particularly maximum catch tube pressure, drag shield deceleration levels, and location of drag shield inside the catch tube when zero velocity was attained, were evaluated and compared with predicted results.

A secondary objective of this checkout was to provide data on drag shield position and velocity versus time. To obtain this information, camera targets were installed at 24-foot intervals on the tower and a test package containing a camera was fastened to the floor so that the targets could be filmed as the shield passed. Analysis of the camera film provided a displacement history at discrete points during the drop and continuously during deceleration.

For the second phase of the checkout tests, the experimental package was allowed to float free in the drag shield. The test objectives were to:

1. Evaluate the operation of the test package components during the low gravity environment and the deceleration phase.

2. Establish relative motion characteristics between drag shield and experimental package.

3. Evaluate test preparation and check-out procedures, and package instrumentation.

During all check-out drops significant parameters characteristic of the drag shield, experiment package, and catch tube were recorded. A list of measurements is contained in Table I.

Test Results

The overall performance of the drop facility was verified in the 28 check-out drops. All intended test objectives were accomplished and the verification and development of the facility to an operational stage was considered complete.

The tests performed during first phase of the checkout were numbered A1 through A12 and are listed in Table II. The 70-inch diameter drag plate was installed on the drag shield for test A10. Tests A11 and A12 were performed to evaluate the ability of the cameras on the stand to provide information on the attitude of an internal package during a drop; however, the stand camera arrangement eventually proved to be less effective than a single camera mounted on the package itself because of camera film speed limitations.

The catch tube was considered the most critical component of the facility. Its performance during checkout exceeded expectation, particularly the functioning and durability of the seals. Initially some rebound resulted from a residual over-pressure after the shield passed the last seal and forward motion had stopped. This was not considered serious with regard to the drag shield itself, but could have damaged the test package. Therefore, appropriate modifications were necessary to eliminate the rebound.

Figures 11 and 12 show the measured drag shield position history and catch tube pressures for drop tests A8 and A10 respectively, which were made from the full drop height of 294 feet. As illustrated in Figure 11, the drag shield rebounded approximately seven feet. Prior to test A10, however, two additional orifices were cut near the bottom of the tube and the test results in Figure 12 demonstrate that practically no rebound occurred. It is of interest to also note that the drag shield/package combination decelerated to zero velocity in less than .4 seconds. The tube pressure attained a maximum of about 13 psig in both tests.

The second phase tests and some results are listed in Table III. Typical decelerations measured on both the test package and the drag shield are shown in Figure 13. The deceleration of the test package oscillates above and below that of the drag shield because the test package was not completely settled on the drag shield floor prior to deceleration. The maximum measured decelerations were approximately 21 g_o on the test package and 18 g_o on the drag shield.

Figure 14a shows the relative displacement and velocity history measured during a test with a package acceleration of .032 g_o (Test B15).* For this test, the drag brake was installed and a retro thrust of 20.6 lb was applied for the first two seconds of drop (Table III). The internal package lifted off the floor almost immediately, rose to a maximum height of approximately 1.3 feet, then settled on the floor .37 second before the drag shield entered the catch tube. The low gravity test duration during this drop was 4.01 seconds. The drag shield reached the catch tube 4.357 seconds after release. These figures are considered typical of this facility.

The effect of the drag brake during test B15 can be estimated by comparing tests A9 and A10 (Table II). A drop time difference of .039 seconds results and can cause a deviation in drag shield location of 2.75 feet or more in 4.354 seconds.

PROBLEMS

The problems encountered during the facility checkout and their solutions are briefly described below:

*Figure 14b shows the package g-level measured and that calculated using the programmed ratio of package thrust to weight.

1. Since the rate of drag shield descent varies slightly due to rail friction and aerodynamic drag, which in turn are somewhat dependent on weather conditions, highly accurate analytical predictions of experimental package and drag shield displacement histories were not attained. Therefore, the establishment of proper test conditions and sequencing has been accomplished through a combination of "trial and error" and analytical procedures. However, as illustrated in the Chrysler Report (HSM-R32-67), the analytical procedures are of considerable value in establishing conservative test conditions whenever new experimental package acceleration levels are necessitated.

2. Rotation of the package about a horizontal axis during the drop occurred in some of the initial tests. As illustrated in Figure 14C, the packages rotated a maximum of approximately 7 degrees about the camera sight axis. This problem was eliminated by using improved balancing procedures that: (a) compensated for the change in thrust pressure bottle weight due to gas outflow during a drop, and (b) improved the thrust nozzle alignment accuracy.

FACILITY UTILIZATION

Some of the experimental studies that have been or will be conducted in the MSFC facility include:

Present and Past Studies

1. Slosh wave amplification due to sudden acceleration decreases (Reference 2).
2. Slosh waves due to lateral impulses (Reference 3).
3. Interface formation time.
4. Propellant Draining termination.
5. Propellant control with dielectrophoresis.
6. Performance of liquid-vapor sensors.
7. Boiling heat transfer.

Future Studies

1. Surface tension and capillary devices.
2. Propellant transfer.

Because of the versatility in the low acceleration levels obtainable, experiment size, and test frequency, many other experiments will eventually be conducted in the facility in support of the Apollo Applications Program and others.

APPENDIX

Characteristic Times for Low Gravity Fluid Behavior

An assessment was made to determine whether or not the low gravity period provided by the MSFC drop tower would allow sufficient time for the observation of various low gravity phenomena. Times characteristic of two basic phenomena were evaluated, the time required for a low gravity liquid-vapor interface to form and the period of a slosh wave cycle.

Whenever a liquid-vapor interface is subjected to a sudden transition from a normal gravity environment to that of low gravity the interface moves through and oscillates about its equilibrium configuration. At the time the drop tower design was in progress, the only existing criteria for interface formation time was that developed by Lewis Research Center (Reference 4). This criteria provided an estimate of the time required for the surface centerpoint to move from its normal position through the zero gravity position for the first time. This characteristic time (t) is related to the density (ρ), container diameter (D) and liquid surface tension (σ) through the following equation:

$$t = K(\rho/\sigma)^{1/2} D^{3/2}$$

K = .17 for spheres
K = .14 for cylinders

For a fluid simulating liquid hydrogen this surface formation time is 1.8 seconds in a six-inch diameter cylinder. Although this does not represent the total surface formation time, it was reasoned that the 4.3 seconds of drop time would be adequate for the interface to form.*

Since low gravity slosh was of primary interest in the drop tower program, the slosh wave period had to be such that at least one slosh

*Subsequent testing proved that this relation does not apply to non-zero gravity environments and that significantly more time may be required for the surface to attain equilibrium.

cycle could be observed during a test. The slosh period in a cylindrical container can be calculated using the following relation developed by Satterlee and Reynolds (Reference 5):

$$t = 2\Pi \left[\frac{\sigma}{\rho R^3} \left(1.5 + 1.84 \frac{\rho a R^2}{\sigma}\right) \right]^{-1/2} **$$

where R = cylinder diameter
a = local acceleration

The Bond Number of interest to the Saturn V program is about 80 and the corresponding slosh period for a six-inch diameter container with a liquid simulating liquid hydrogen is about two seconds. Therefore, it was again reasoned that the facility would allow testing in containers on the order of six inches.

**This relation is valid for zero contact angle liquids and for liquid depths equal to or greater than one tank radius.

TABLE I

INSTRUMENTATION PROGRAM

Measurement Number	Nomenclature	Calibrated Range	Test Effectivity
D-360	Test Package Thruster Pressure	0/1000 psig	B1 & Subs
D-368	Catch Tube Pressure	0/15 psig	All
D-369	Catch Tube Pressure	-5/+15 psig	All
D-391	Drag Shield Thruster Pressure	0/1500 psig	A11 & Subs
A-005	Test Package Low "G" Accelerometer	0/0.2 g	B1 & Subs
A-006	Test Package High "G" Accelerometer	±50 g	B1 & Subs
A-007	Drag Shield Laternal Motion Accelerometer	±25 g	A1 - A12
A-008	Drag Shield Vertical Motion Accelerometer	±25 g	A1 - A10
A-009	Drag Shield Vertical Motion Accelerometer	±25 g	A4 & Subs
K-033	Breakwire-Catch Tube entrance (end of Free Fall Indication)		All
K-041	Indication - Drag Shield Release		B3 & Subs
K-043	Indication - Test Package Release		B4 & Subs

TABLE II

TEST SUMMARY

First Test Phase

Test No.	Free Drop Ht. Ft	Drop Time Sec	Total Drop Wt. Lbs	Max. Tube Pressure psig	Catch Tube Orifice Area Sq ft
A1	32'	1.420	3750	2.6	3.0 (#6 open)
A2	80'	2.242	3750	4.8	3.0 (#6 open)
A3	104'	2.583	3750	5.1 (1)	3.0 (#6 open)
A4	104'	2.565	3820 (2)	6.1	3.0 (#6 open)
A5	152'	3.092	3820	7.0	4.5 (#6 open) (#7-1/2 open)
A6	200'	3.550	3820	8.7	4.5 (#6 open) (#7-1/2 open)
A7	248'	3.962	3820	10.9	4.5 (#6 open) (#7-1/2 open)
A8	294'	4.315	3820	12.8	6.0 (#6 & #7 open)
A9	294'	4.317	3820	13.2	4.5 (#7 & #8 open)
A10	294'	4.354	3880 (3)	13.0	4.5 (#7 & #8 open)
A11	294'	4.312 (5)	3616 (4)	14.2	4.5 (#7 & #8 open)
A12	294'	4.314 (6)	3616 (4)	13.5	4.5 (#7 & #8 open)

TABLE II

First Test Phase
(Concluded)

(1) Drag Shield plexiglas windows failed at this pressure

(2) Weight change due to Drag Shield window modifications.

(3) Weight increase due to addition of Drag Plate.

(4) Weight decrease due to removal of test package.

(5) 91.75# direct thrust applied to drag shield for 3.91 seconds.

(6) 80.35# direct thrust applied to drag shield for 3.95 seconds.

TABLE III

TEST SUMMARY SHEET

Second Test Phase

Test No.	Drag Shield Weight Pounds	Drag Shield Thrust Pounds	Test Pack. Weight Pounds	Test Pack. Thrust Pounds	Test Pack. Start Position Inches	Drag Shield Drop Time Seconds	Test Pack. Free Fall Time Seconds	Max. Tube Press. psig
B1 (1)	3616	-----	264.5#	-----	9" above floor	-----	------ -	-----
B2 (1)	3616	-----	"	-----	15" above floor	4.315	.993 (2)	-----
B3 (1)	3616	-----	"	-----	"	4.357	.752 (3)	-----
B4 (1)	3616	-----	"	-----	"	4.345	.884 (4)	-----
B5	3616	-----	"	-----	"	4.355	2.919 (5)	14
B6	3616	-----	"	-----	"	4.345	2.356 (6)	14
B7	3616	-----	"	8.7#	On floor	4.353	4.4+	11.8
B8	3616	-16# (10)	"	8.65#	"	4.362	4.4+	13.7
B9	3616	-17.9# (10)	"	8.1#	"	4.368	3.829	12.3
B10	3616		"	8.4#	"	4.365	4.044	14.1
B11	3616	-16.9# (10)	257#	7.3#	"	4.365	3.932	14.1
B12	3616	-16.5# (11)	257#	8.0#	1" above floor	4.363	4.4+ (7)	14.3
B13	3700(9)	-37# (10)	271#	8.5#	On floor	4.371	3.337	13.3
B14	3700	-41.2# (11)	271#	8.5#	On floor (180°)	4.373	3.413	12.3
B15	3700	-20.6# (10)	271#	8.55#	"	4.357	4.010	12.3
B16	3700	-20.6# (10)	271#	8.6#	1" above floor	4.360	4.4+ (8)	12.4

TABLE III

TEST SUMMARY SHEET

Second Test Phase
(Concluded)

(1) Purpose of these tests was to set release sequence. Due to short Free Fall times, most data were not evaluated.

(2) Test Package released approximately .041 seconds prior to drag shield.

(3) Test Package released approximately .043 seconds prior to drag shield.

(4) Test Package released approximately .040 seconds prior to drag shield.

(5) Drag Shield released .017 seconds prior to test package.

(6) Drag Shield released .013 seconds prior to test package.

(7) Drag Shield released .003 seconds prior to test package.

(8) Drag Shield released .023 seconds prior to test package.

(9) Weight increase due to stiffening of Drag Shield Floor and addition of thruster system components.

(10) Thrust on for first two seconds after release.

(11) Thrust on for first three seconds after release.

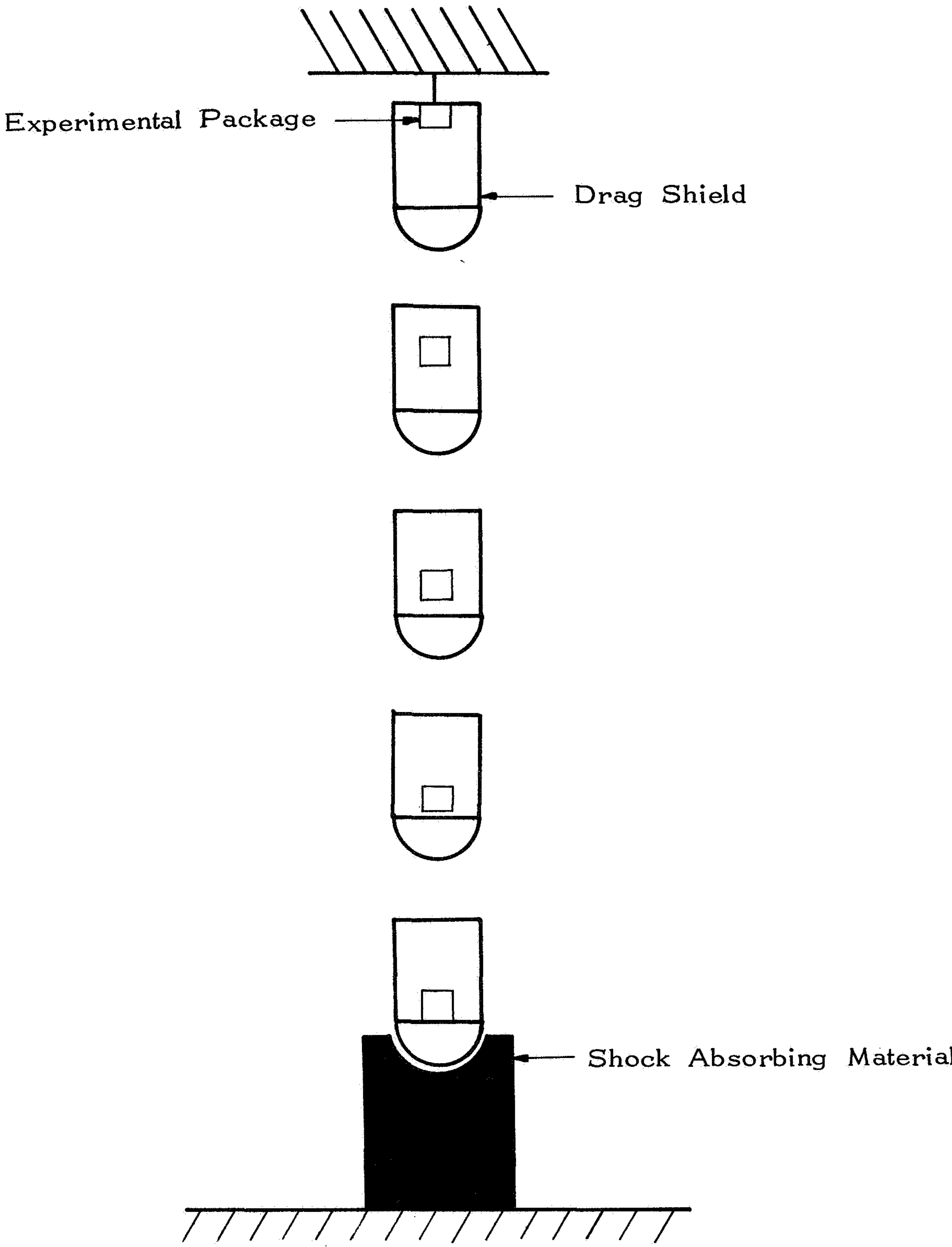


FIGURE 1. TYPICAL DROP TOWER OPERATION

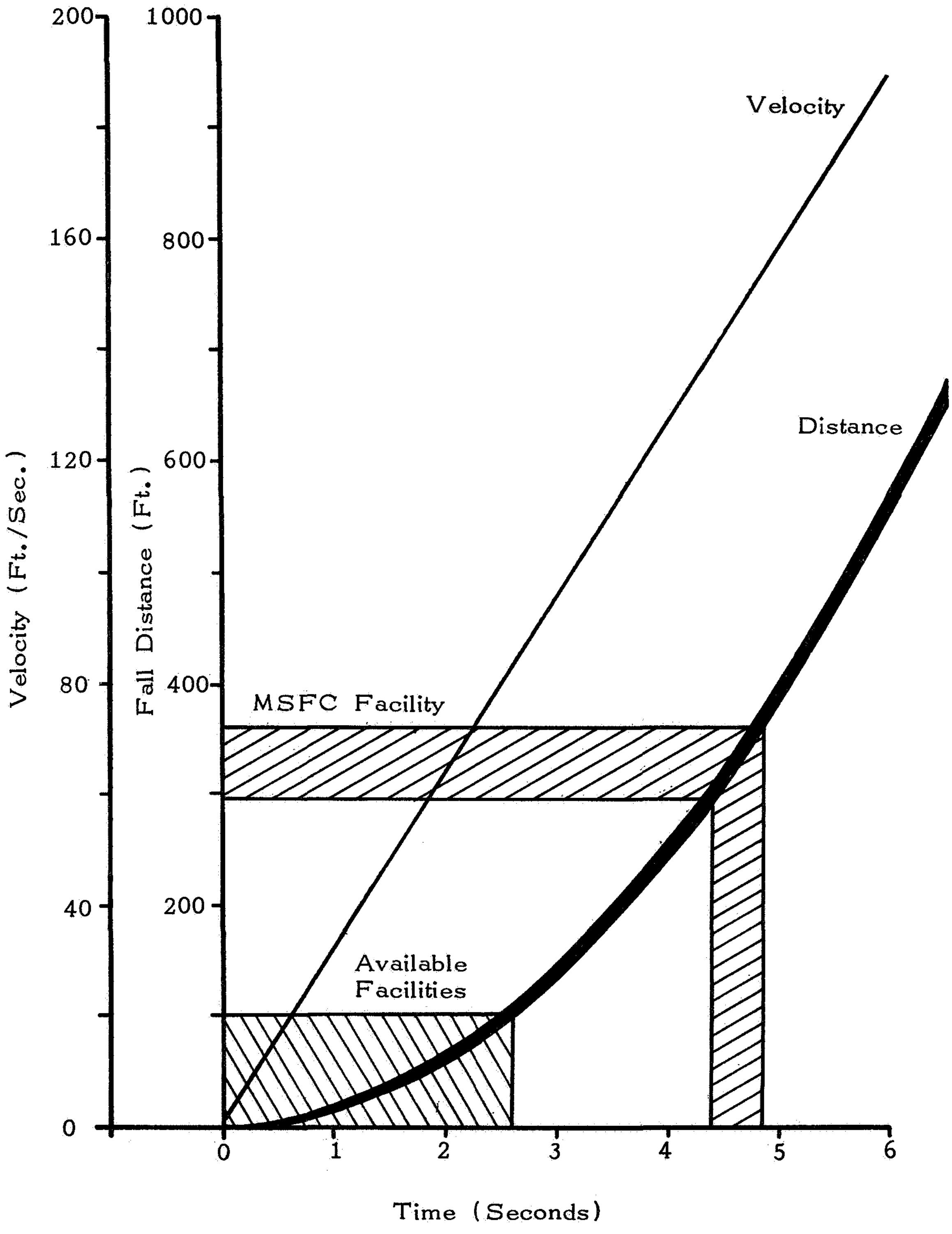


FIGURE 2. FREE FALL VELOCITY AND DISTANCE HISTORY.

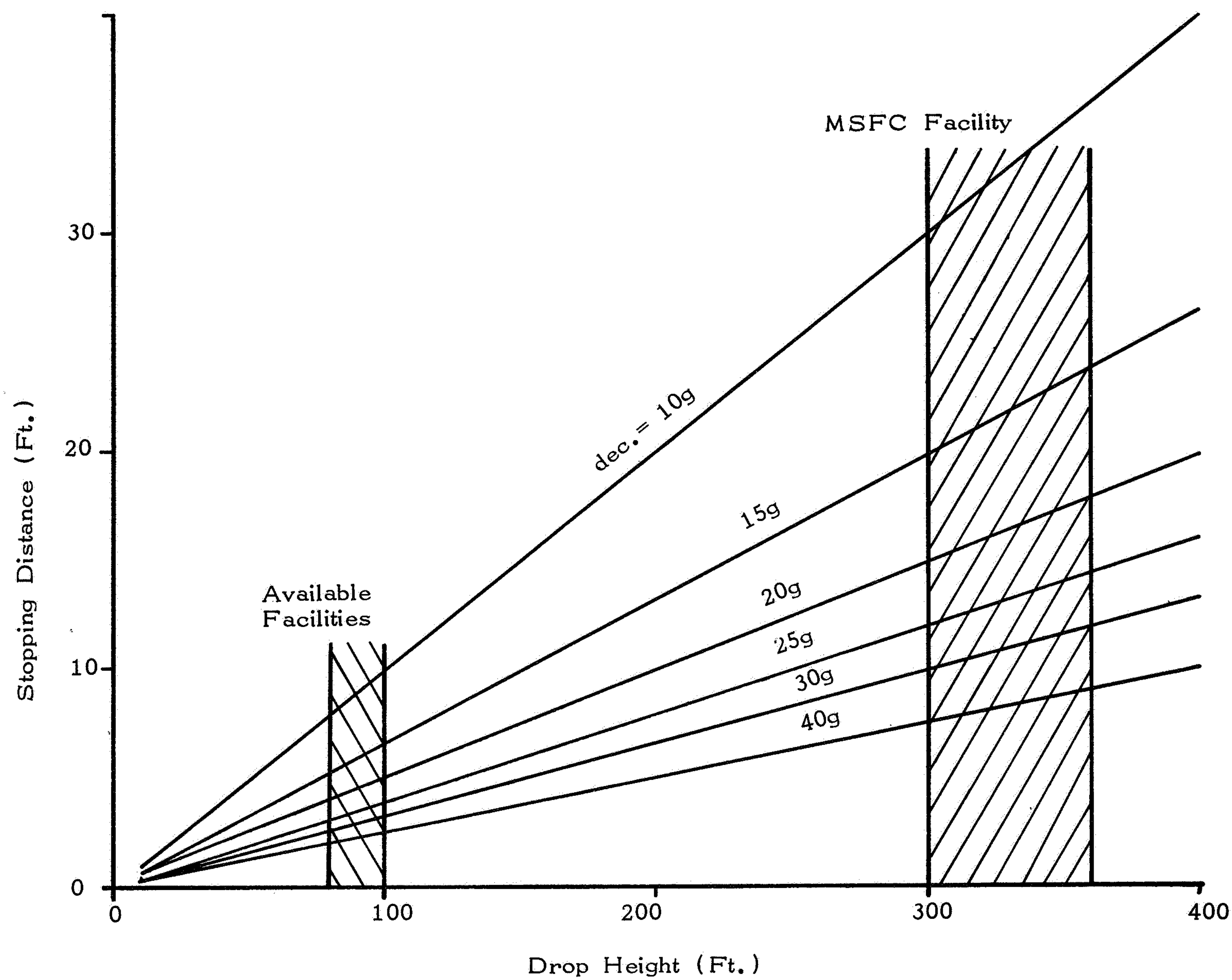
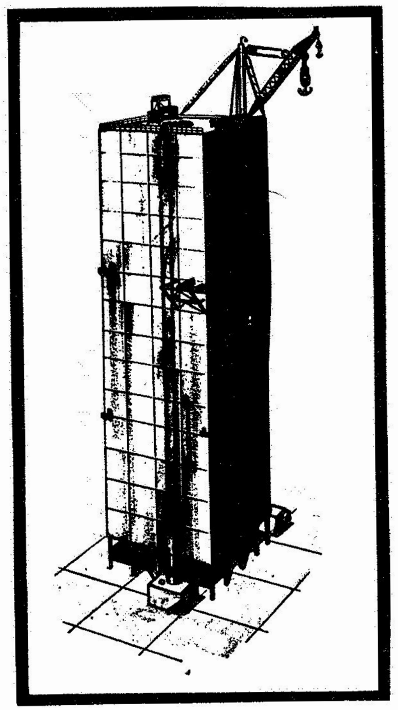
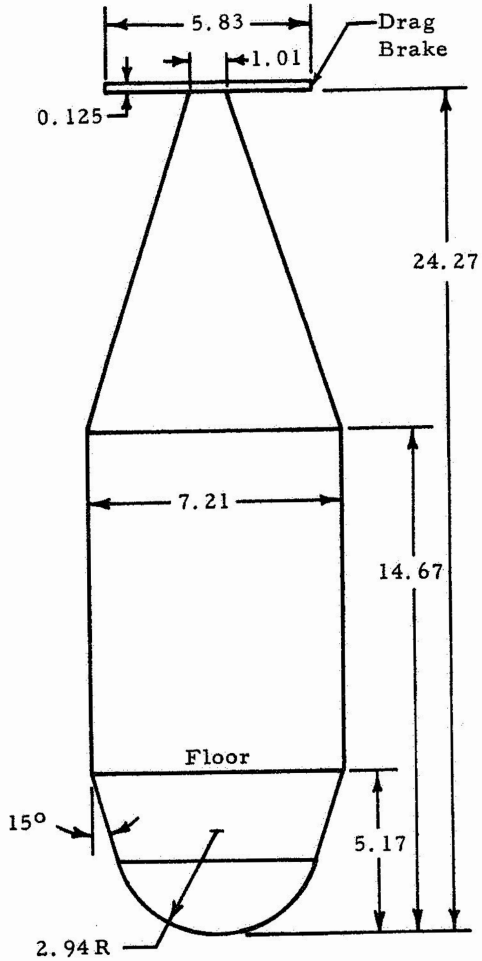


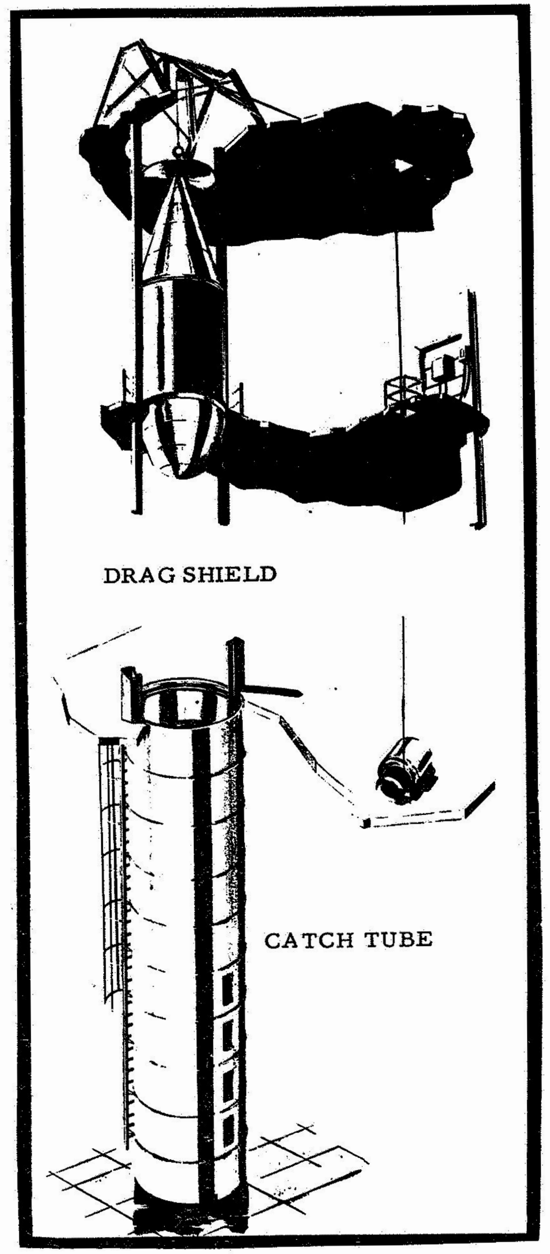
FIGURE 3. UNIFORM DECELERATION STOPPING DISTANCE WITH DROP HEIGHT.



SATURN V DYNAMIC
TEST STAND



DRAG SHIELD



DRAG SHIELD

CATCH TUBE

FACILITY CAPABILITIES

PAYLOAD	450 lbs.
LOW GRAVITY TEST RANGE	
MINIMUM	10^{-5} g_o
MAXIMUM	4×10^{-2} g_o
DROP TIME	4.3 sec.
TOTAL DROP WEIGHT	4000 lbs.
MAXIMUM TEST PACKAGE	3' dia. x 3' high
DECELERATION	less than 25 g's

FIGURE 4. MARSHALL SPACE FLIGHT CENTER LOW GRAVITY TEST FACILITY

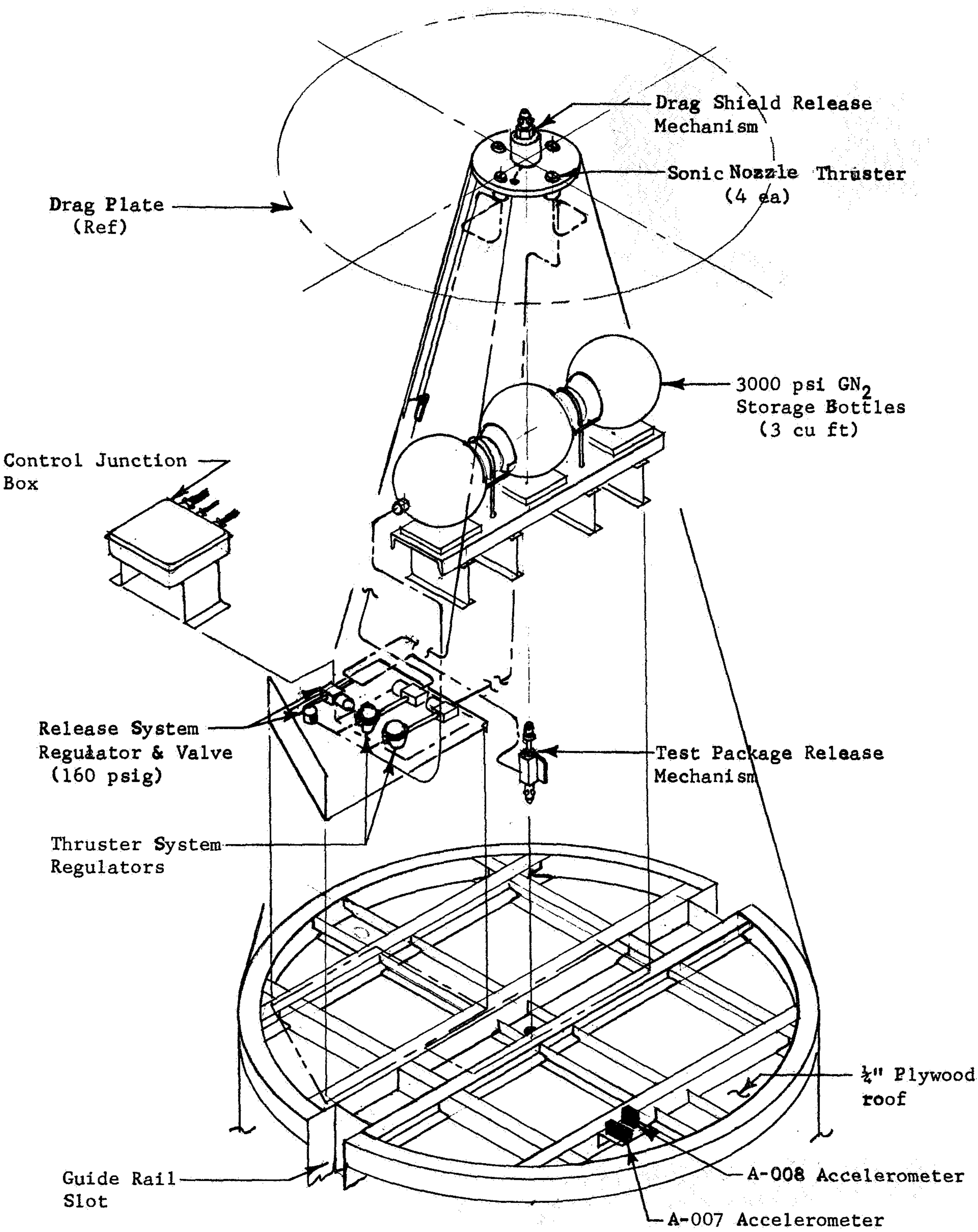


FIGURE 5. FIXED EQUIPMENT ARRANGEMENT — TAIL CONE.

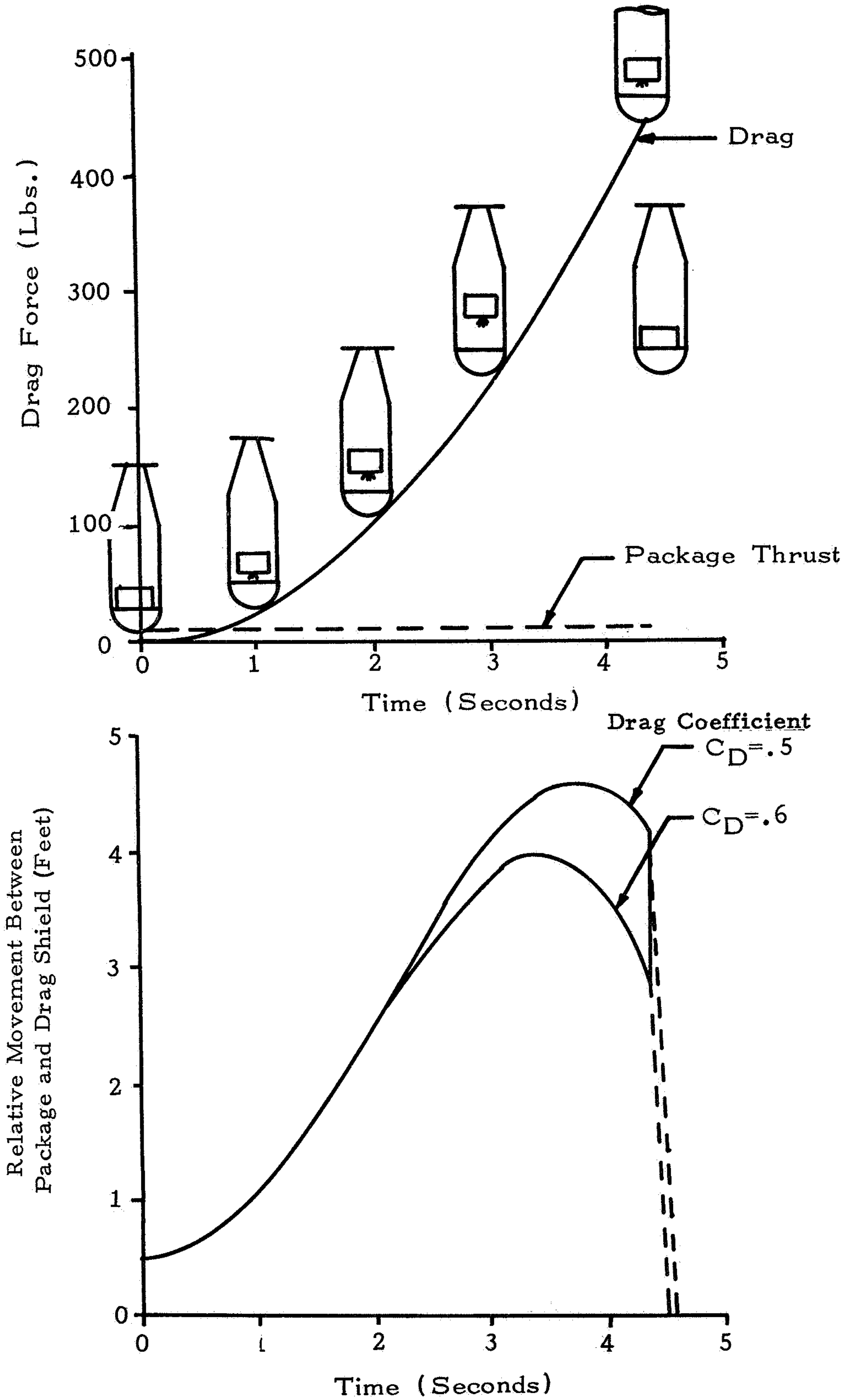
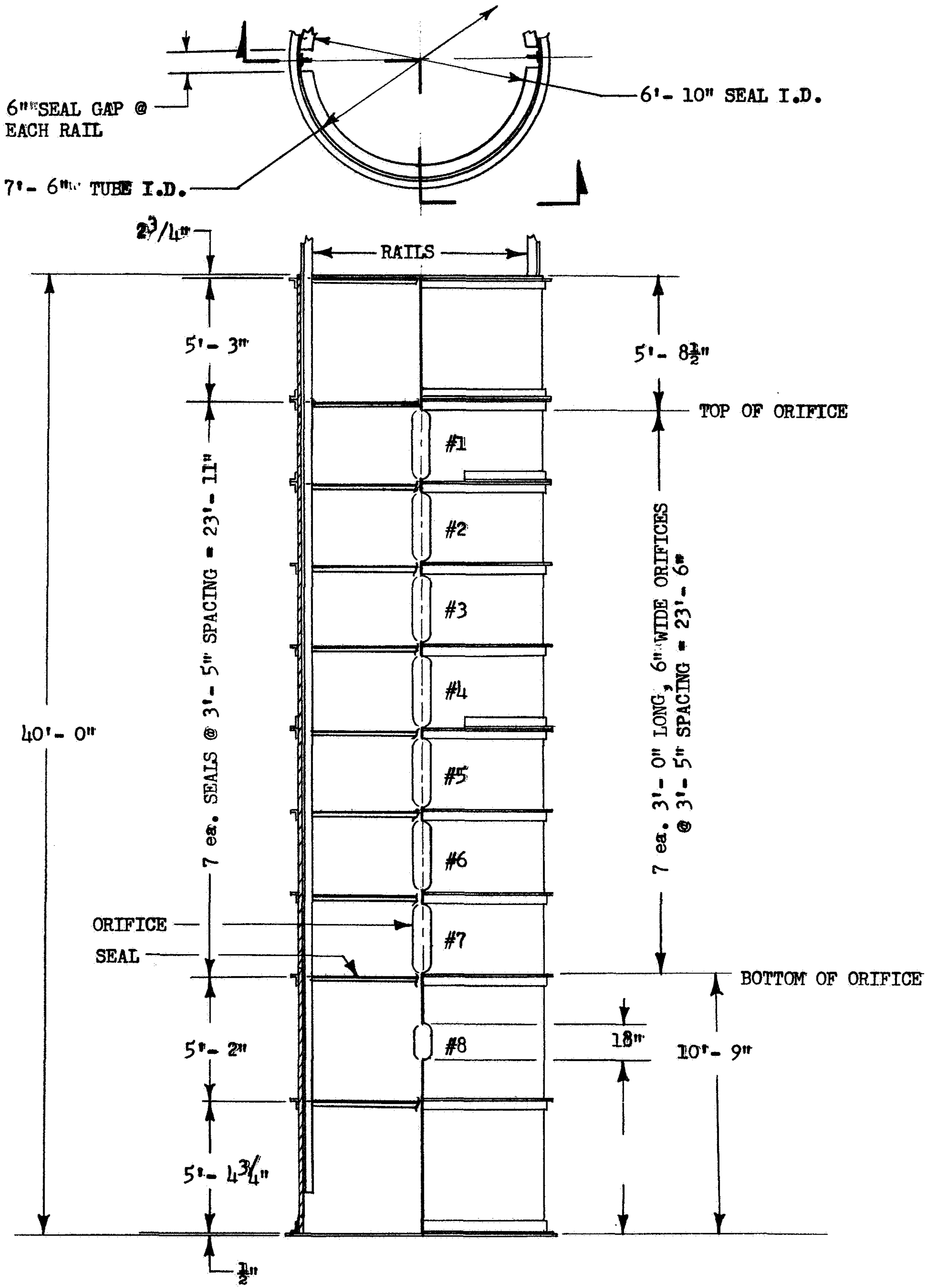


FIGURE 6. PREDICTED DRAG AND RELATIVE MOTION HISTORY.



GURE 7. CATCH TUBE DIMENSIONS.

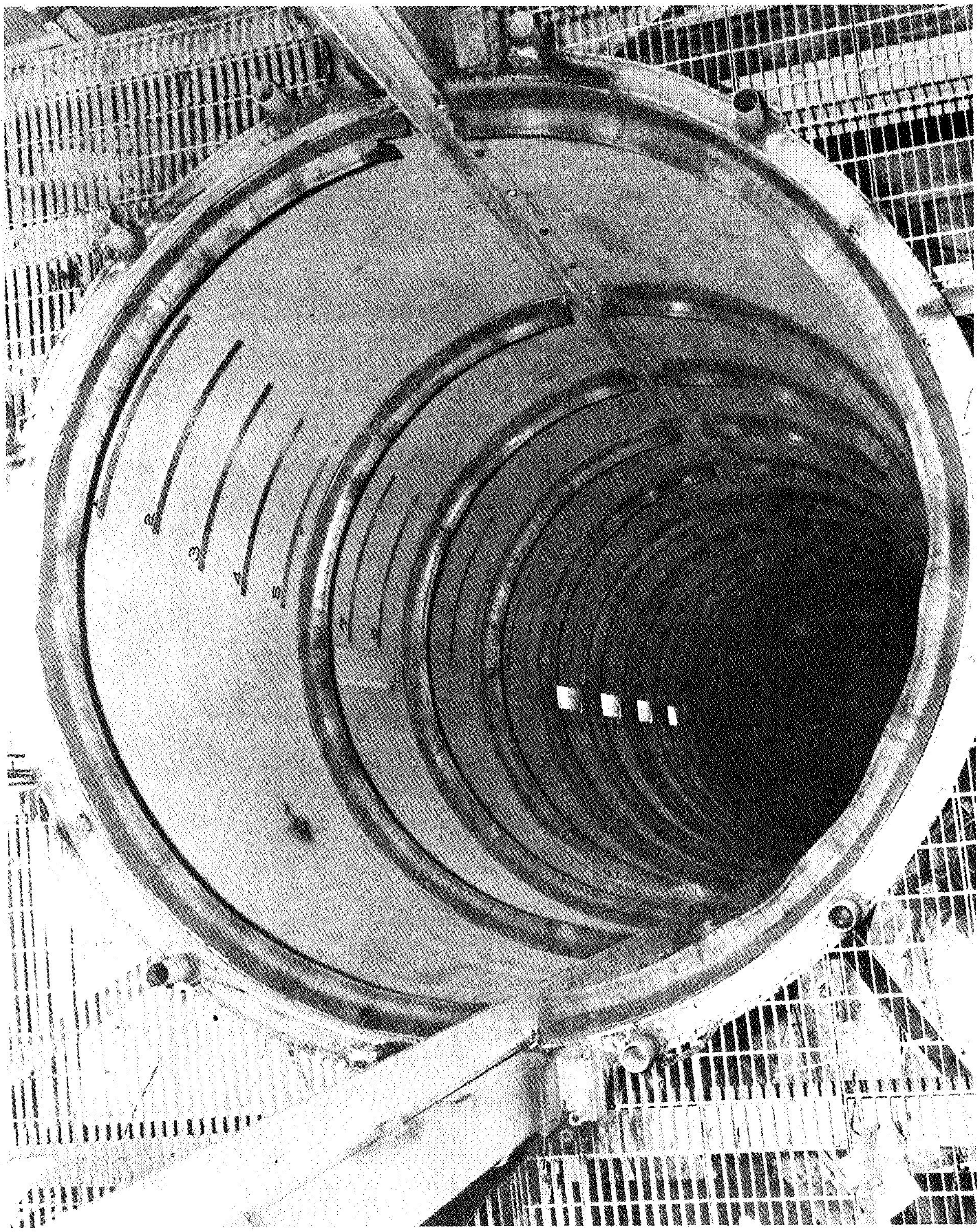


FIGURE 8. INTERIOR OF CATCH TUBE.

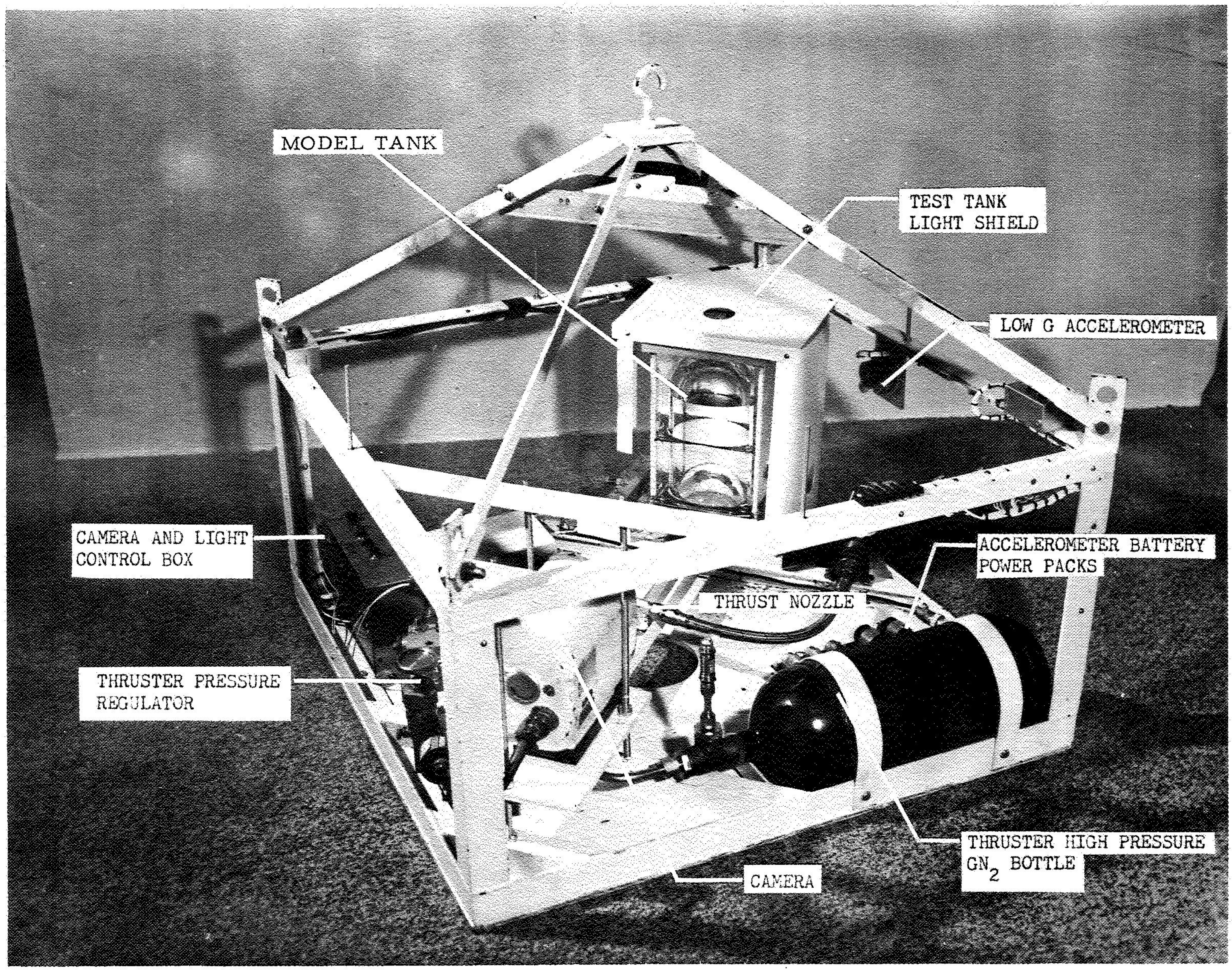


FIGURE 9. TEST PACKAGE ARRANGEMENT.

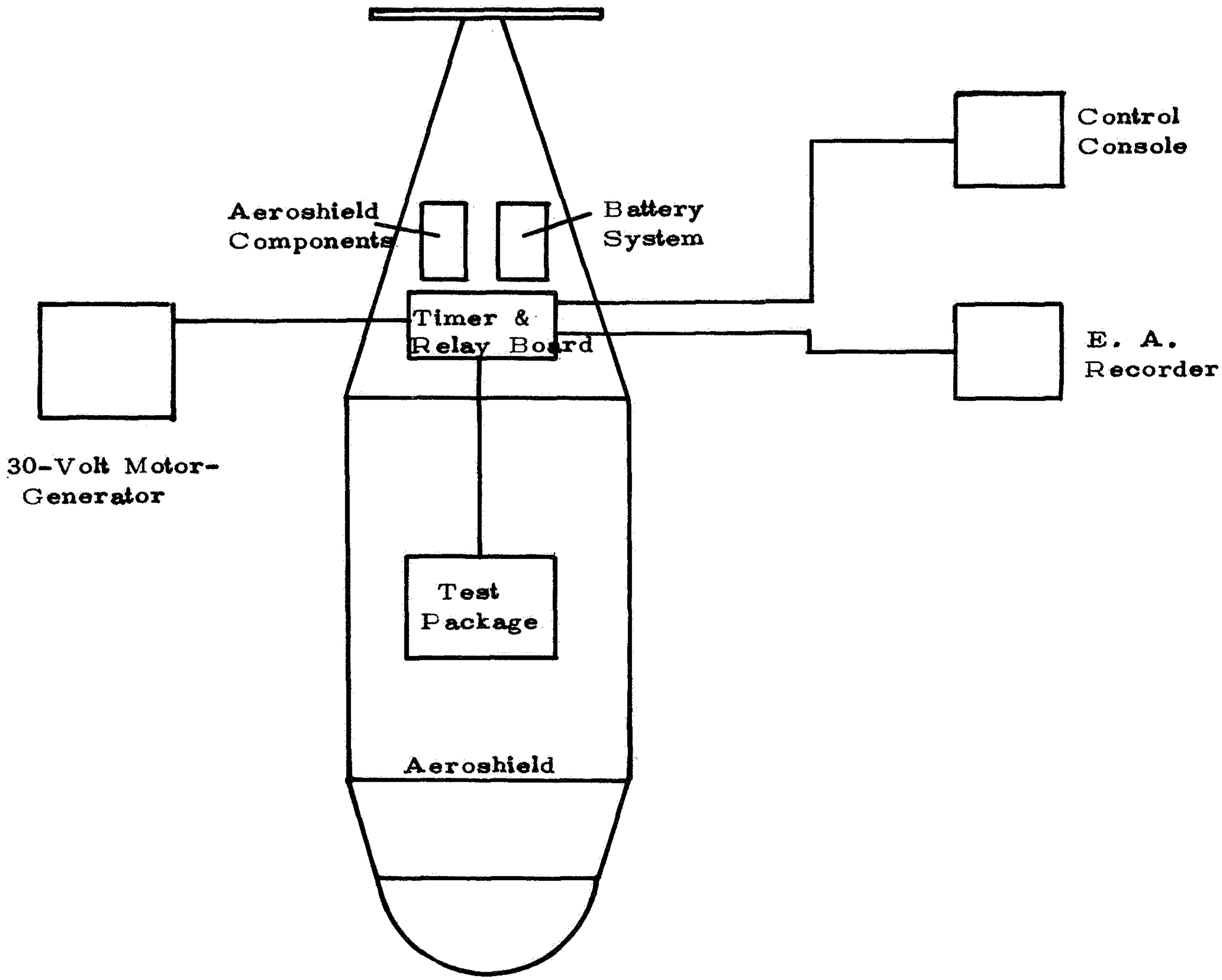


FIGURE 10. TELEMETRY CONTROL SYSTEM SCHEMATIC

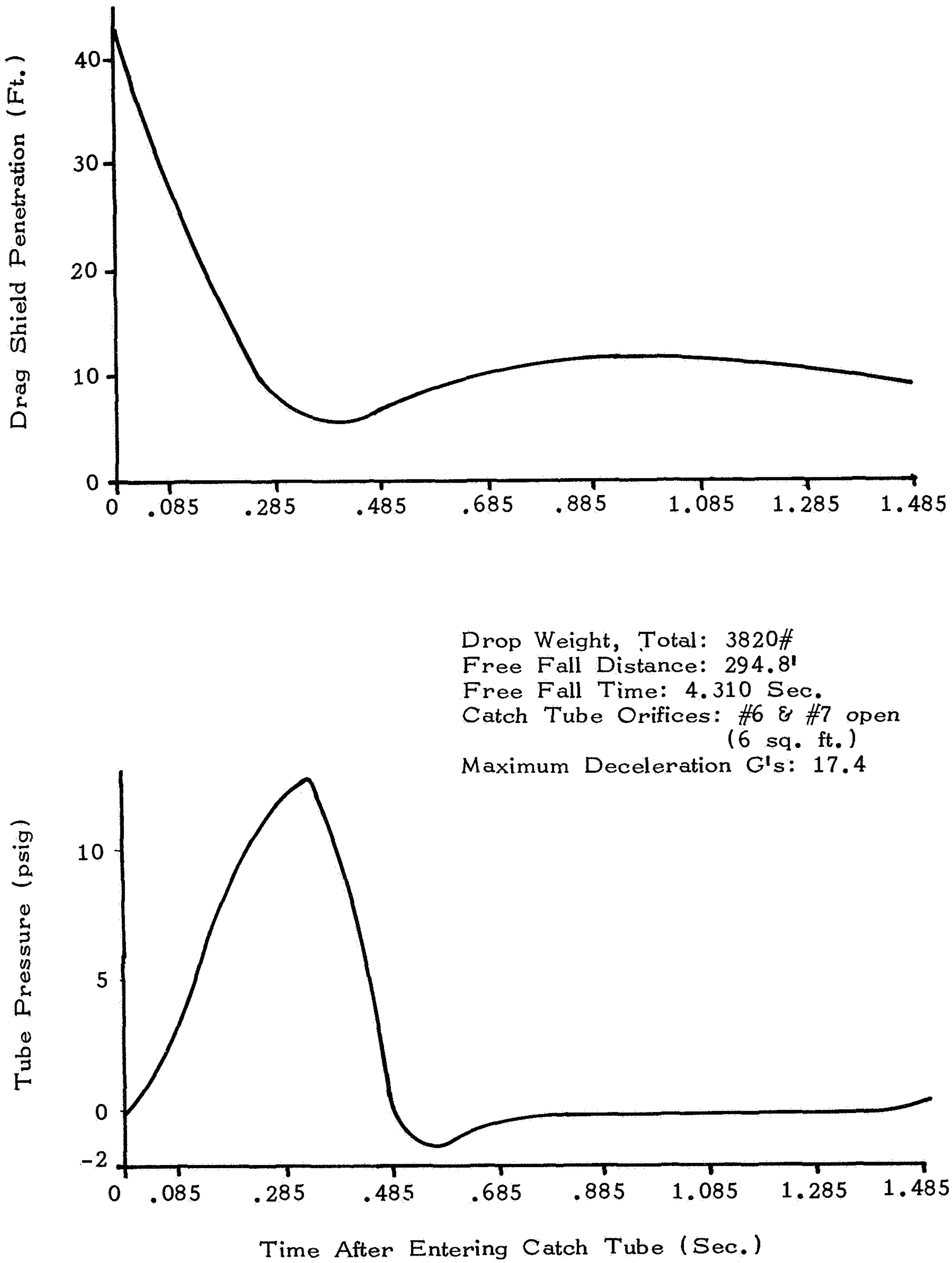
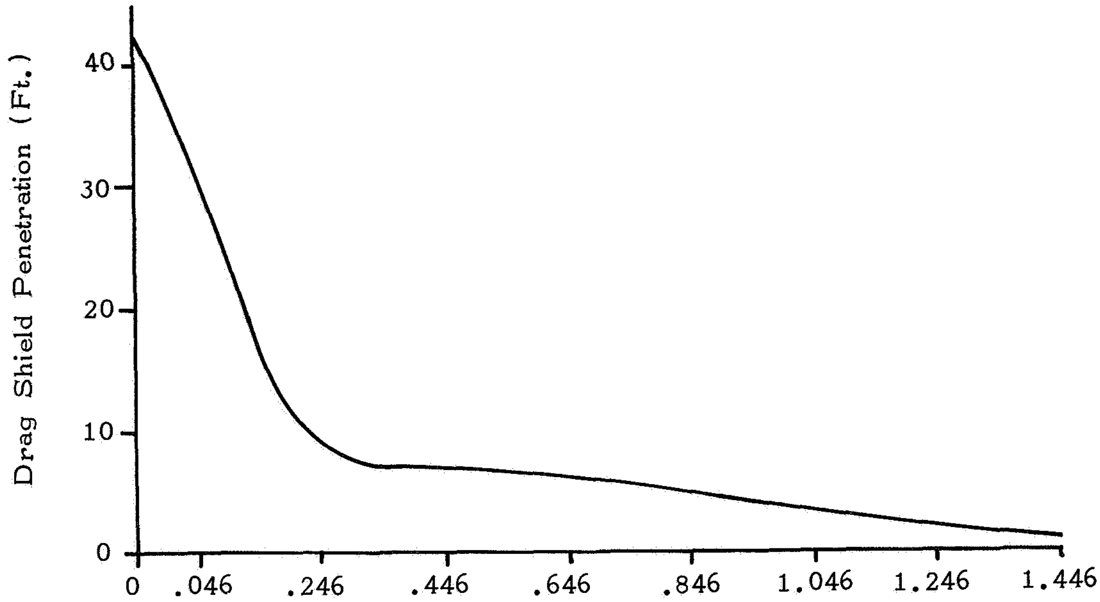


FIGURE 11. CATCH TUBE PERFORMANCE WITH REBOUND. (C-024-2A9)



Drop Weight, Total: 3880#
Free Fall Distance: 294.8'
Free Fall Time: 4.347 Sec.
Drag Plate Installed
Catch Tube Orifices: #7&#8 open
Maximum Deceleration: 15.6 G's

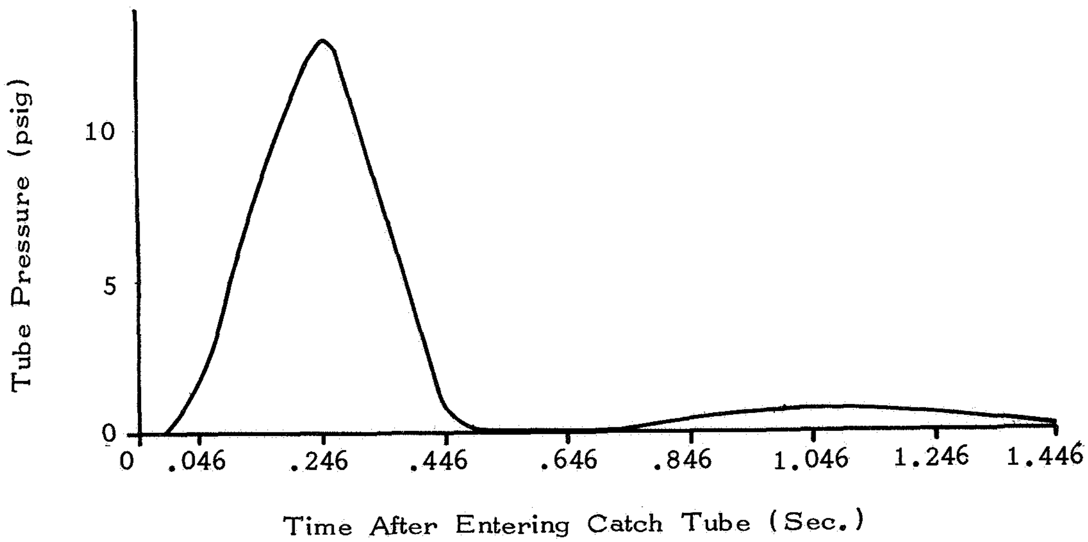


FIGURE 12. CATCH TUBE PERFORMANCE WITHOUT REBOUND. (C-024-2C1)

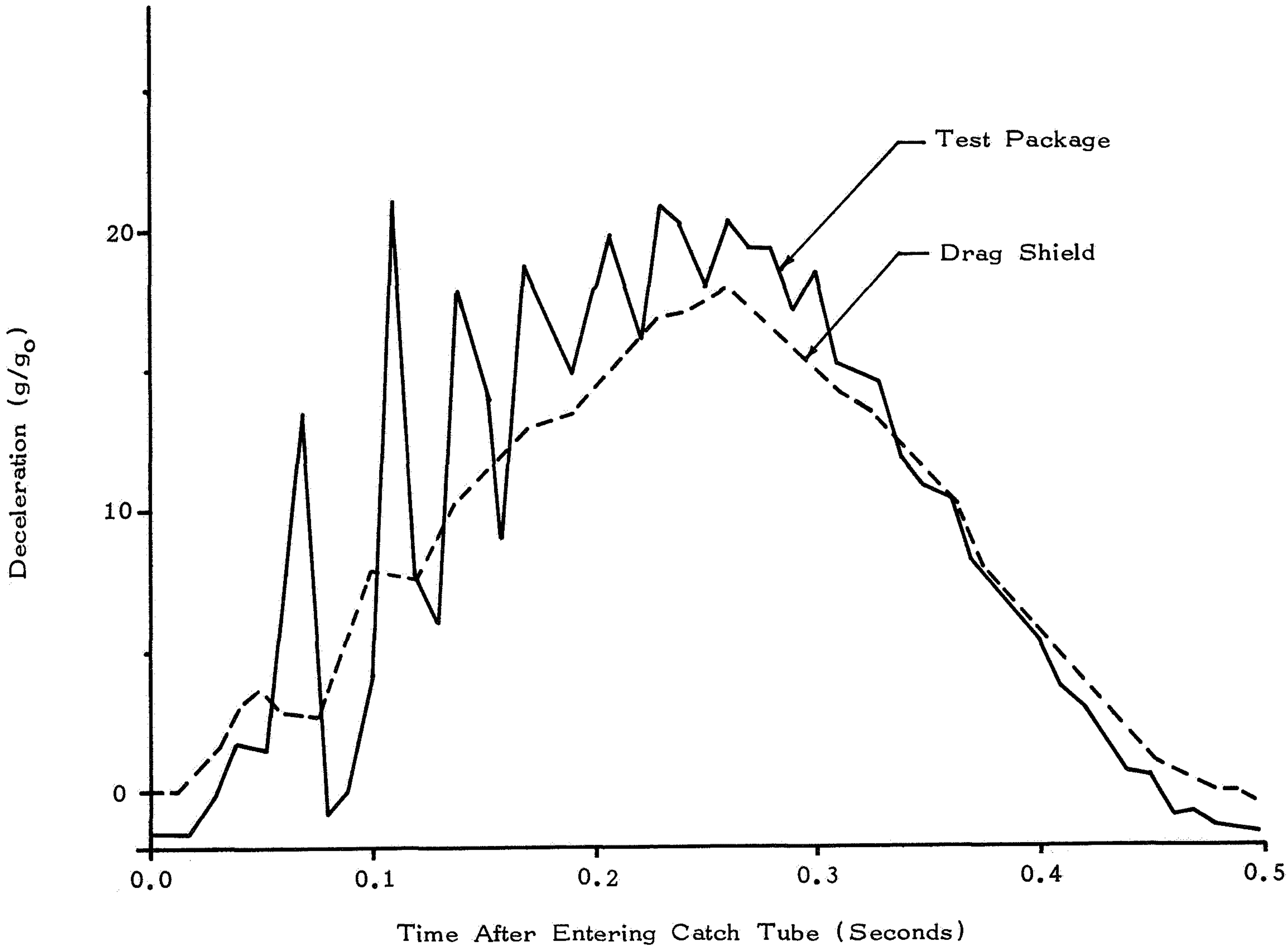


FIGURE 13. TEST PACKAGE AND DRAG SHIELD DECELERATION HISTORY.

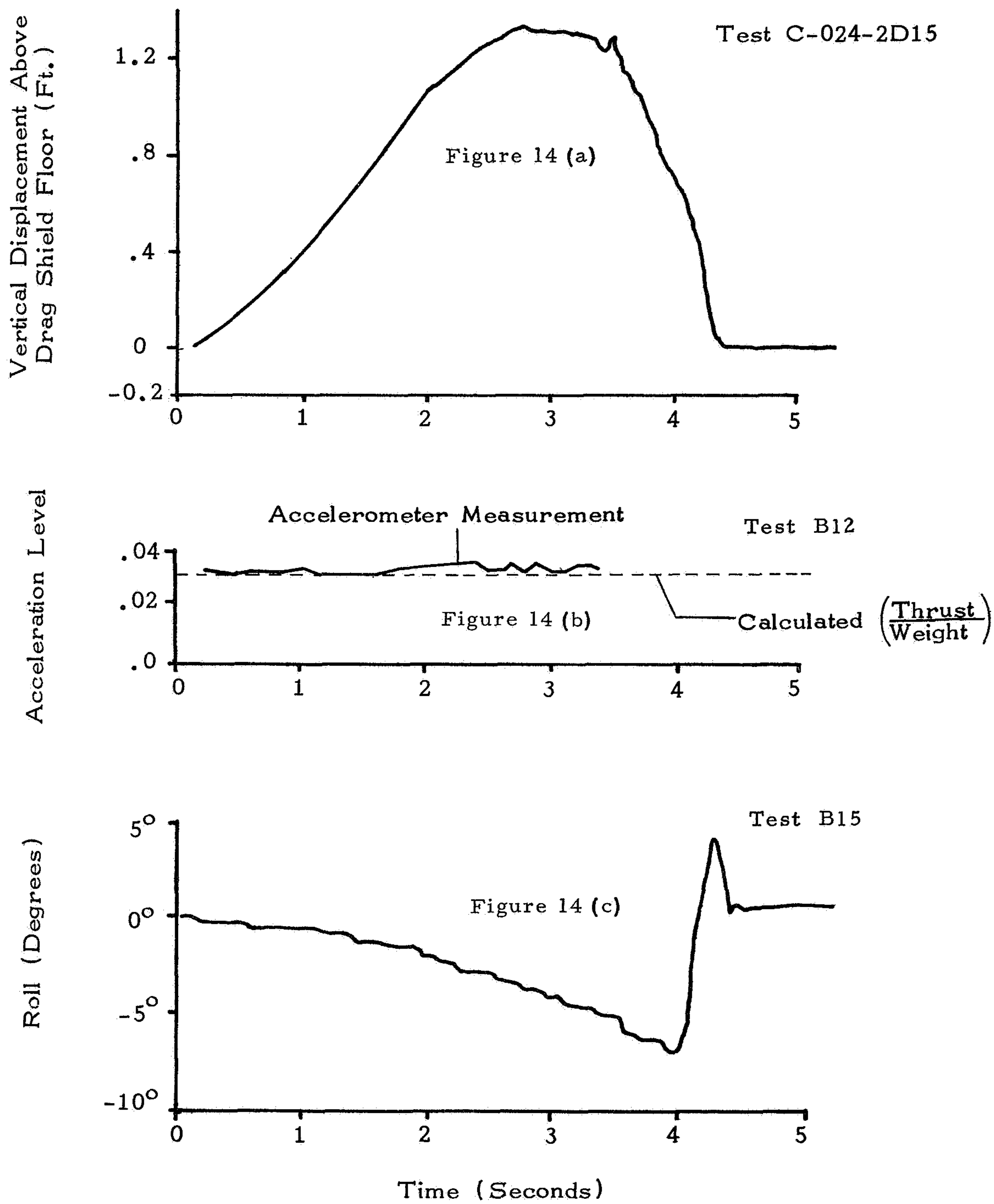


FIGURE 14. (a) RELATIVE DISPLACEMENT, (b) ACCELERATION, and (c) ROLL WITH TIME.

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LOW-GRAVITY FLUID MECHANICS
DROP TOWER FACILITY

By W. B. McAnelly and S. S. Covington

The information in this report has been reviewed for security classification. Review of any information concerning Department of Defense or Atomic Energy Commission programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

This document has also been reviewed and approved for technical accuracy.

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